DURABILITY ASSESSMENT OF WELD SEAMS IN VIRTUAL PROVING GROUND TESTING OF COMMERCIAL VEHICLES

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Universität der Bundeswehr München

MAN

Agenda

Motivation

High number of variants

New battery electric vehicle concepts

No mass production

~7000 busses in 2019

Frontloading in dev. process
Higher level of majority of new concepts
Reduce number of prototypes

City bus

Lion´s City

Lion´s City E

Lion´s City 18 G

Intercity bus

Lion´s InterCity

Coach

Neoplan Cityliner

Lion´s Coach

Neoplan Skyliner

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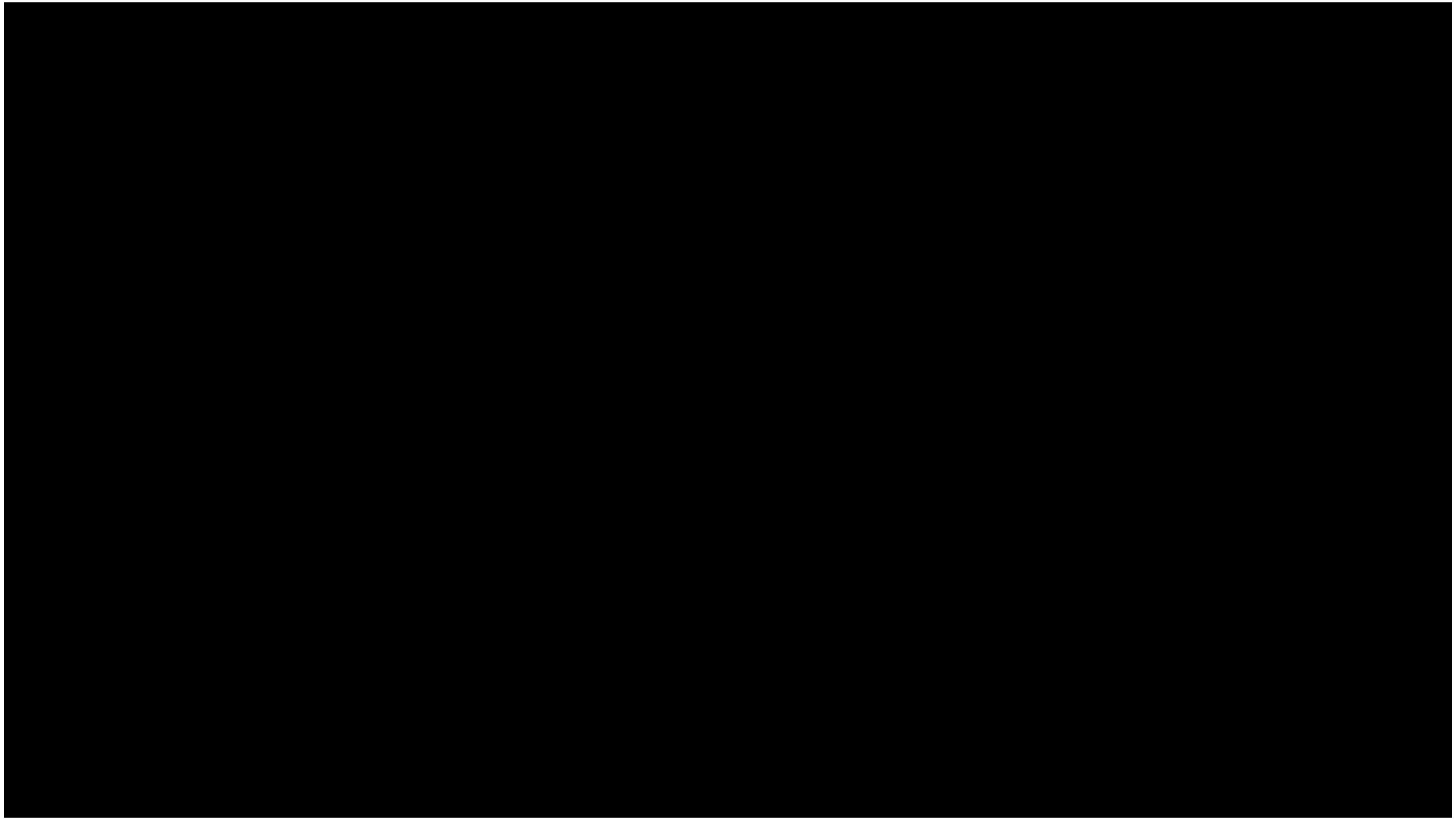
VIRTUAL PROVING GROUND TESTING

Hardware and virtual full vehicle testing at MAN

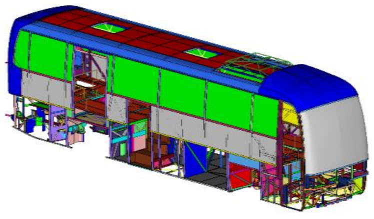


Thanks to the colleagues from EVCD und ECSM (Michael Butz and Joachim Fischer)

Virtual Proving Ground Testing with full vehicle model

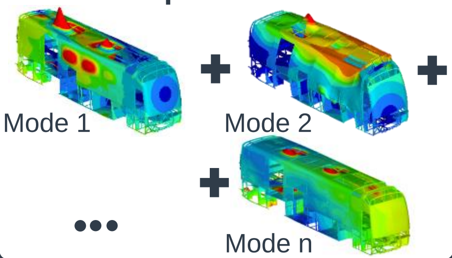
Finite Element

FE Modell strength analysis



Model order reduction

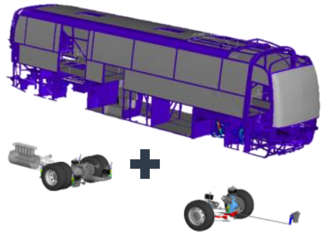
Superelement



Superelement
Eigen- and inertia relief modes

Multibody Simulation

MBS with flexible bodies



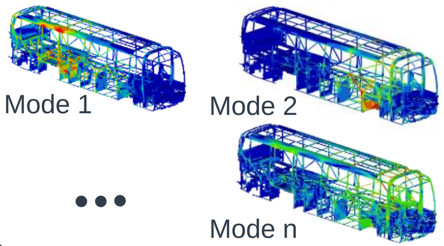
Time integration

Test track ride simulation

Load history
Modal participation factors

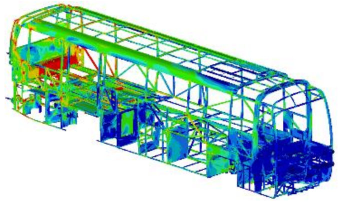
Finite Element

Modal stress tensors



Superposition

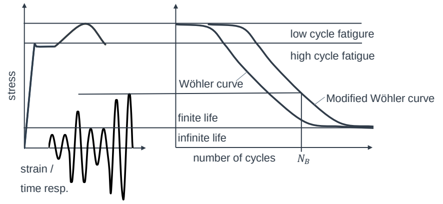
Stress history for the entire structure



Stress history
Stress history for entire structure

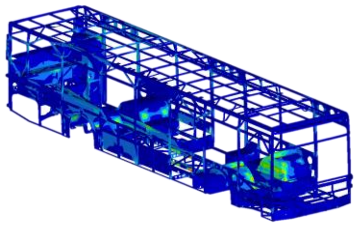
Durability Analysis

Channel Max



Accumulation

Utilization



Utilization
Assessment and optimization

Prototype vehicle and simulation model

City bus prototype

- Weight 10-19 t
- Prototype built for load determination and durability testing

Finite Element

- ~30 Mio. DOF
- 1, 2 & 3D elements
- > 5000 weld seams

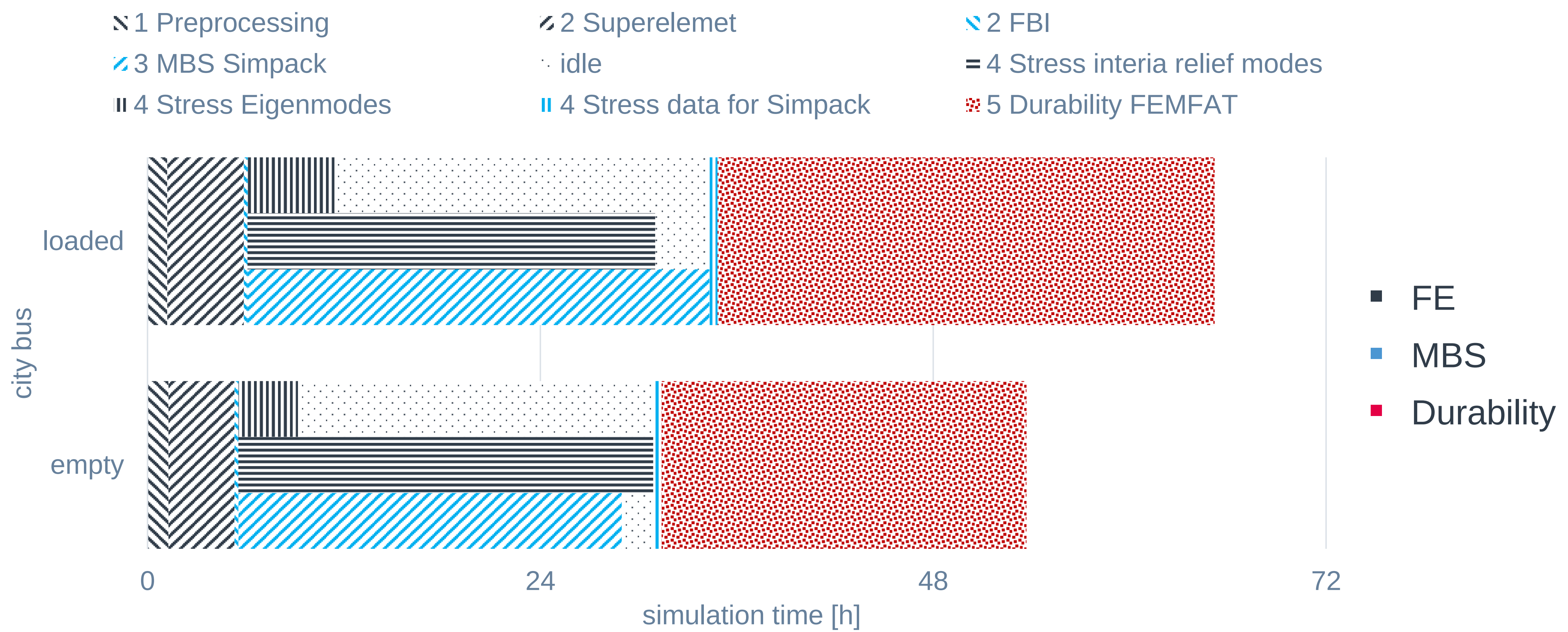
Superelement

- 140 Eigen- /106 IRM modes

Multibody Simulation

- Hybrid MBS model with flexible frame
- ~100 bodies
- Drive train model
- Ftire model

Simulation time on HPC



FEMFAT Simulation time could be reduced by 80% through optimized parallelization in comparison to FEMFAT User Meeting 2019

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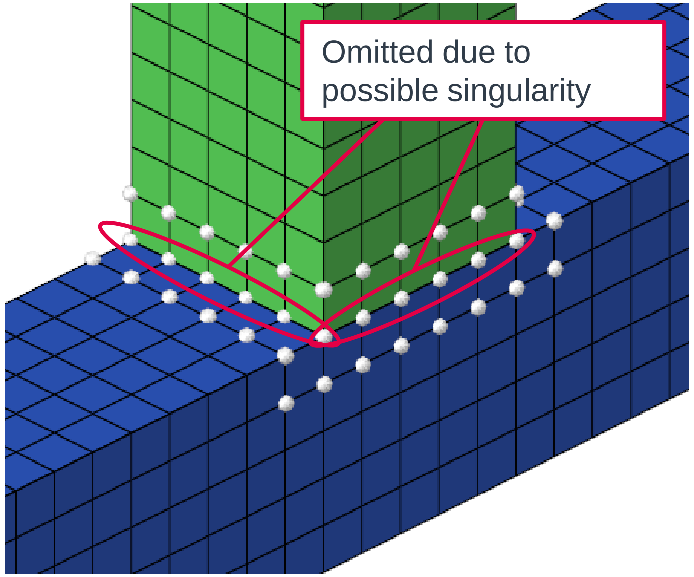
ASSESSMENT OF WELDS

Detection and definition of welds

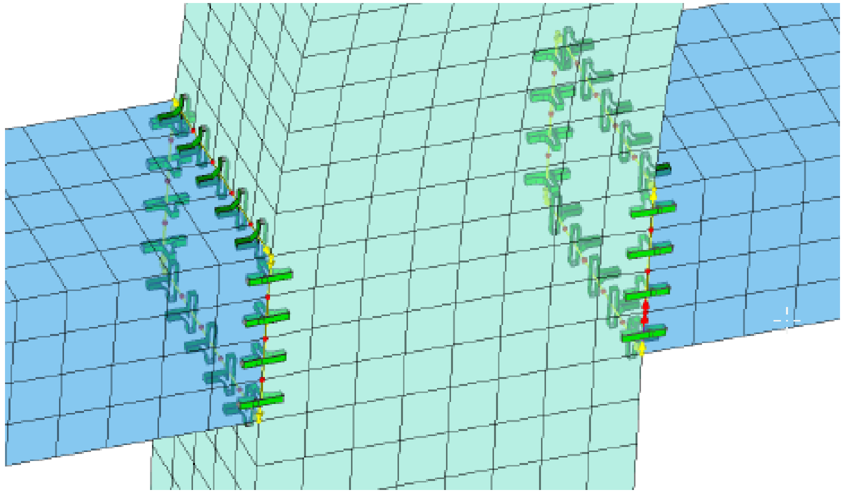
Simplified approach

- Weld seam nodes found with FE-Preprocessor macro based on finite element model topology
- Nodes at junction are omitted due to singularity
- Weld material assignment to remaining weld nodes



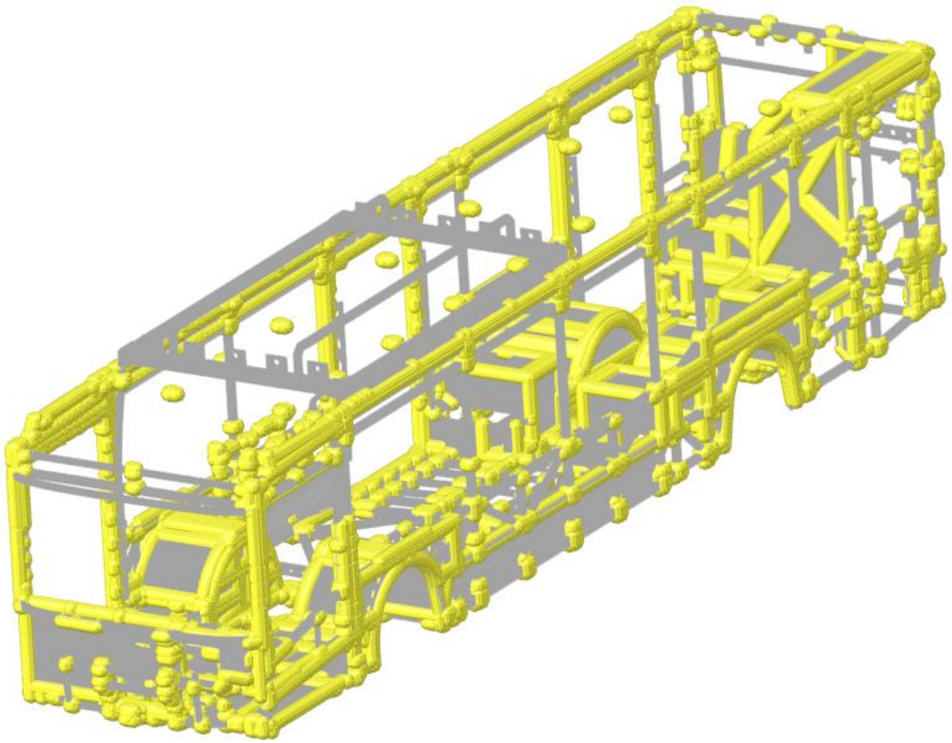
Weld seam scanner

- Scan finite element model for possible weld seam connections
- Weld definition file is generated
- Import weld definition into Visualizer for weld definition (joint type)
- Check and correct automatically defined seams



Detected welds

Weld nodes simplified approach



Simplified fully automated process ✓

Detected weld seams with weld seam scanner

- 5800 weld seams detected

Detailed assessment possible, but check required ✓

Weld assessment procedure

Hot spot screening

Base material hot spots

Simplified approach for weld assessment

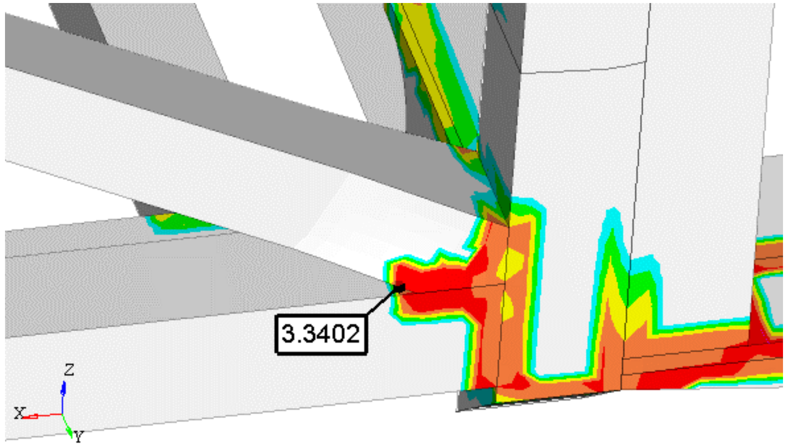
- Fully automated process
- Find critical weld locations

Detailed weld assessment

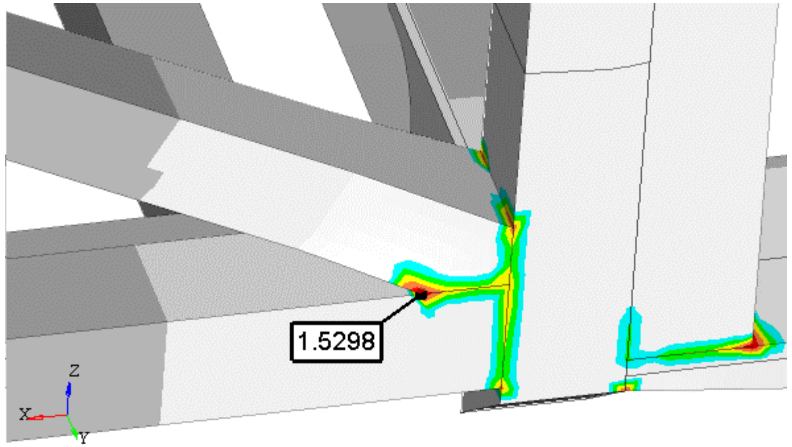
Detect and define weld seams with Weld seam scanner

- Check critical welds and correct type if necessary
  → only critical welds reduces human involvement
- Run FEMFAT with Weld modul for those welds
- Reassess critical welds – realistic utilization

Utilization from hot spot screening



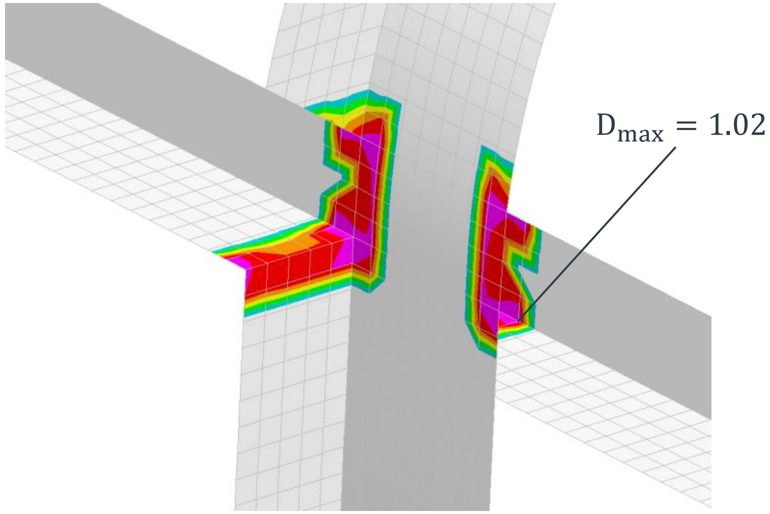
Utilization with detailed weld model



Assessment with simplified approach

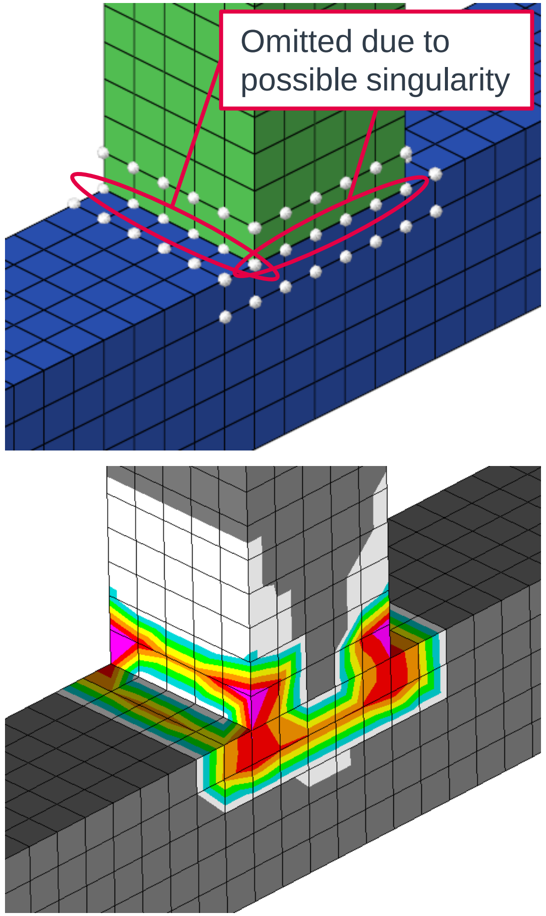
- Critical cutting plane approach (same as base material)
- One calibrated S-N curve for T-junction with component test for all weld nodes
- Nodes at weld seam are not evaluated (singularity)
- Highest ref. Utilization next to weld seam

Calibration with component test



Fokilidis, A.; Savaidis, G.: Experimental investigation of fatigue of thin-walled welded structures of commercial vehicle frames. Thessaloniki: Aristotle University of Thessaloniki, Dept. of Mechanical Engineering, 2007

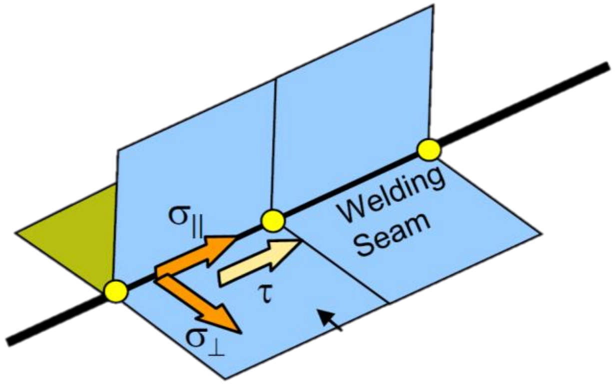
Weld nodes and utilization



Assessment with FEMFAT Weld modul

Transformation of the stresses to a local coordinate system

- $\sigma_{\perp}$ stress perpendicular
- $\sigma_{\parallel}$ longitudinal stress
- τ shear stress



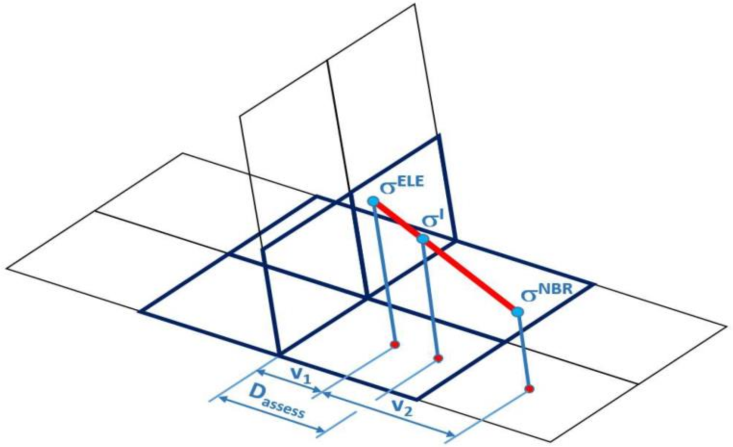
Magna (Hrsg.) Advanced Workshop Weld St. Valentin: Magna, 2019

Structural stress evaluated at fixed distance from weld through interpolation

- Reduces mesh dependency

Assessment

- Detection and definition of welds with Weld seam scanner with manual check
- Assessment with hot spot or notch stress approach

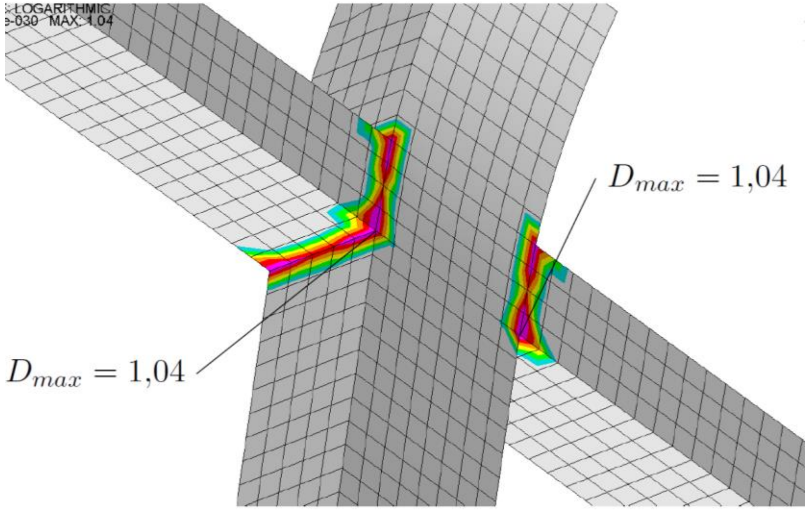


Magna (Hrsg.): FEMFAT 5.4 - BASIC: User Manual. St. Valentin: Magna, 2019

Hot spot stress approach

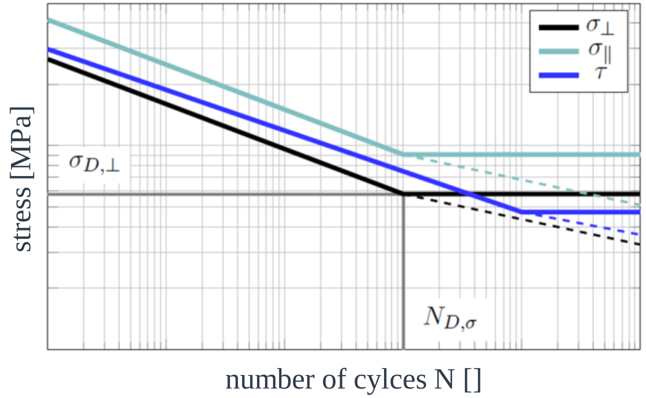
- Assessment of structural stress at defined distance through interpolation
- Separate set of S-N curves for each weld type necessary
  - Scaling with fictive notch factors for integration in FEMFAT
- Calibration of S-N curve with component test

Calibration with component test

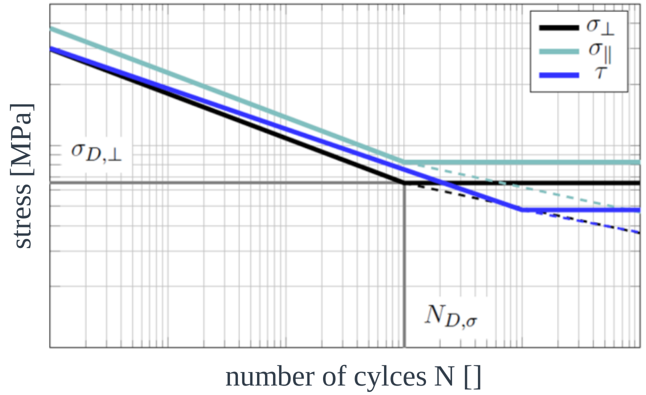


Fokilidis, A.; Savaidis, G.: Experimental investigation of fatigue of thin-walled welded structures of commercial vehicle frames. Thessaloniki: Aristotle University of Thessaloniki, Dept. of Mechanical Engineering, 2007

S-N curve T-joint



S-N curve HY-seam



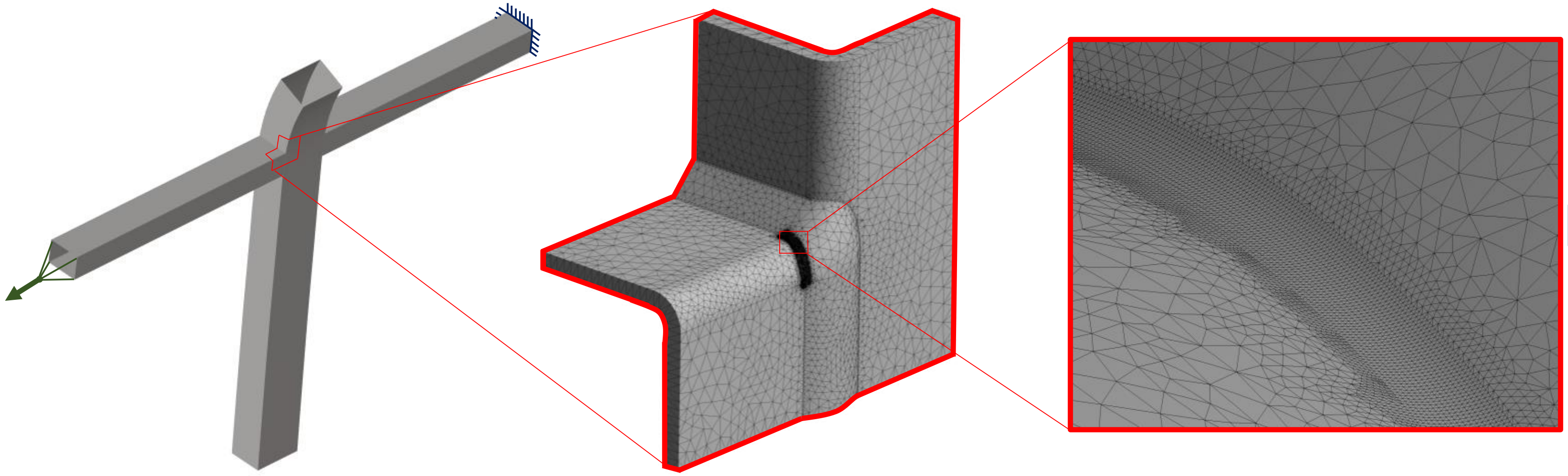
Notch stress approach

- Assessment of structural stress at defined distance through interpolation
- Multiplication of structural stress with type dependent notch factors

$$\sigma_{notch} = \sigma_{structural} * \beta_{notch}$$

- One S-N curve for all weld types of same material
- Standard FEMFAT database was found too conservative for thin sheets

  → Notch factors determined with 3D detail model



$$\beta_\perp \qquad \beta_\parallel \qquad \beta_\tau$$

$$\sigma_\perp = \sigma_{\perp,struct}\,\beta_\perp$$

$$\sigma_\parallel = \sigma_{\parallel,struct}\,\beta_\parallel$$

$$\tau = \tau_{struct}\,\beta_\tau$$

FE model for notch factor determination

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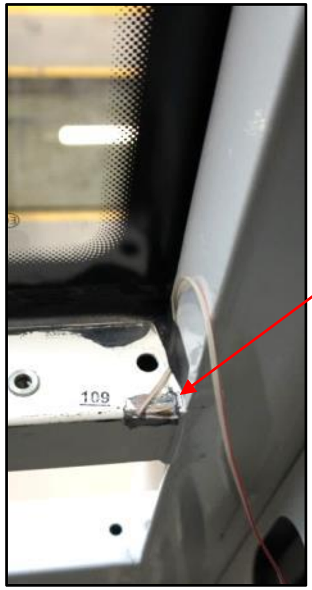
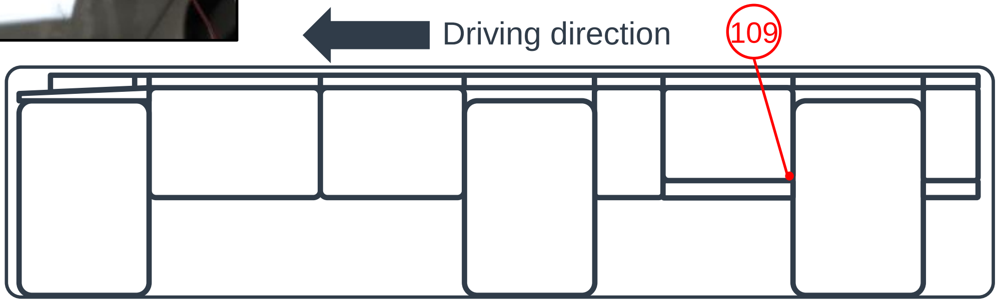
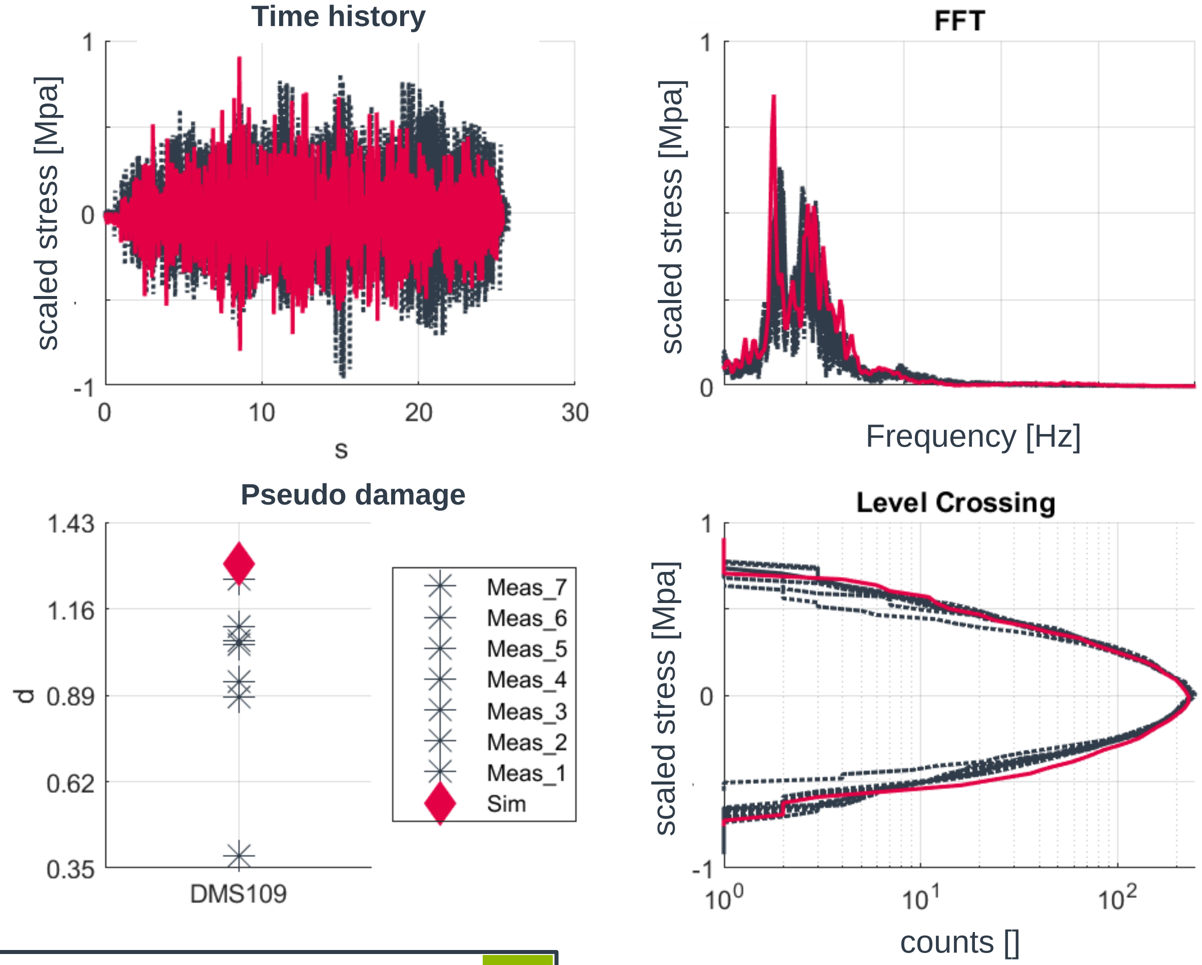
COMPARISON SIMULATED AND MEASURED STRESS

Comparison of stress results







Good correlation in time and frequency domain → similar damage potential ✓

Comparison Pseudo Damage for 72 locations

Pseudo-damage

Basquin-equation

$N = \alpha S^{-k}$

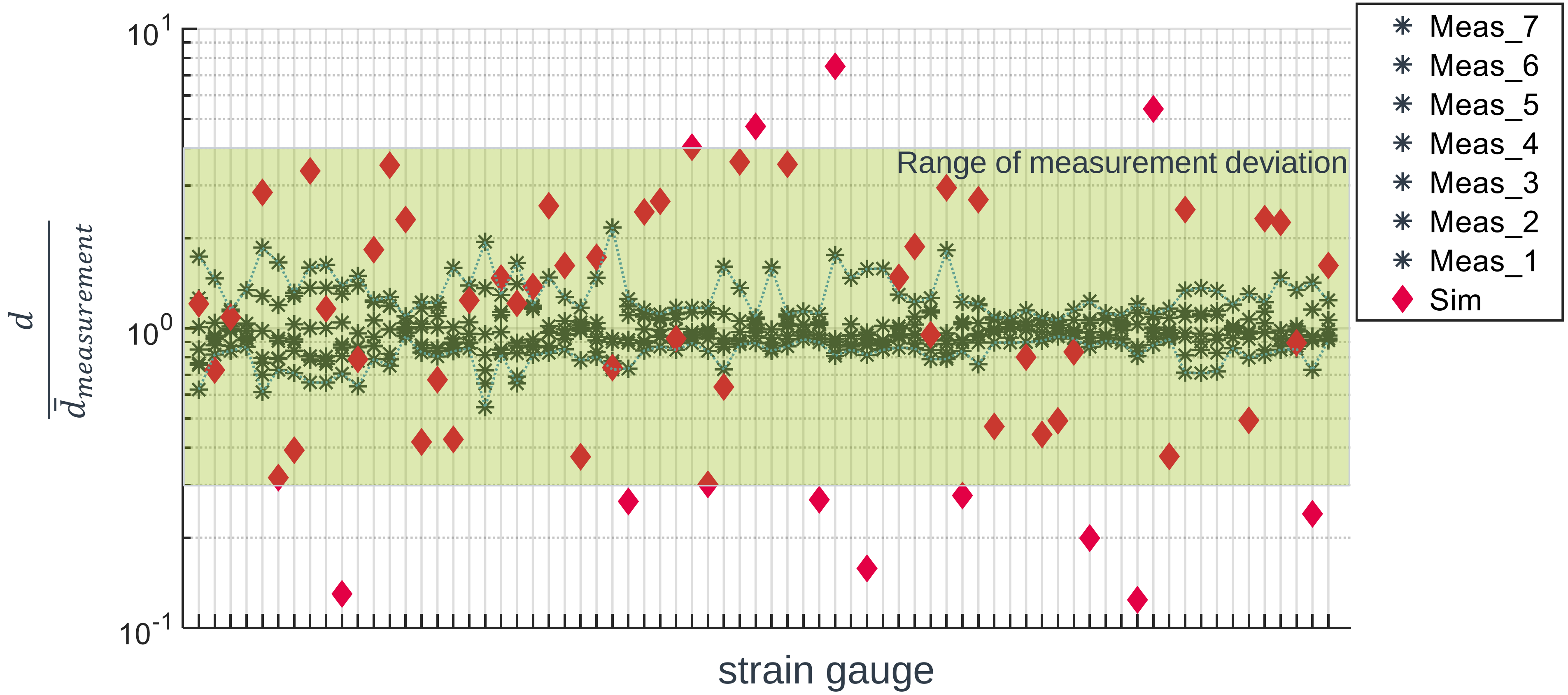
- S stress amplitude
- α constant factor
- k inclination of S−N curve

Cumulative damage D

$$D = \sum_i \frac{n_i}{N_i} = \frac{1}{\alpha} \sum_i n_i S_i^k$$

Pseudo damage d

$$d = \sum_i n_i S_i^k$$



Overall good correlation for stresses in time domain and damage potential ✓

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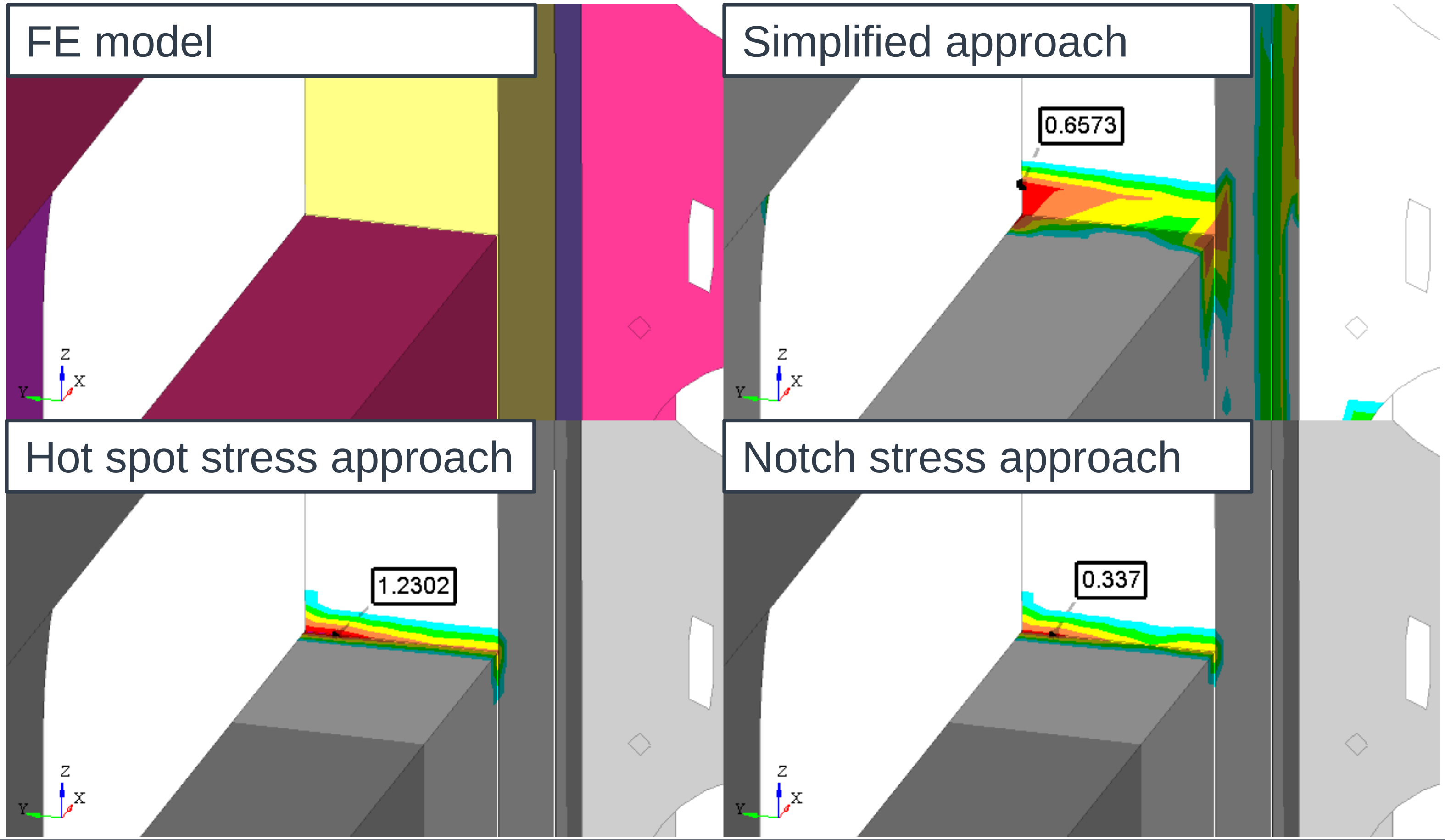
COMPARISON OF DURABILITY RESULTS

Simulated and real world testing utilization

Proving ground testing	Virtual proving ground testing
 Degree of utilization a=5.5	

Good correlation between simulation and testing ✓

→ Weld model for detailed analysis

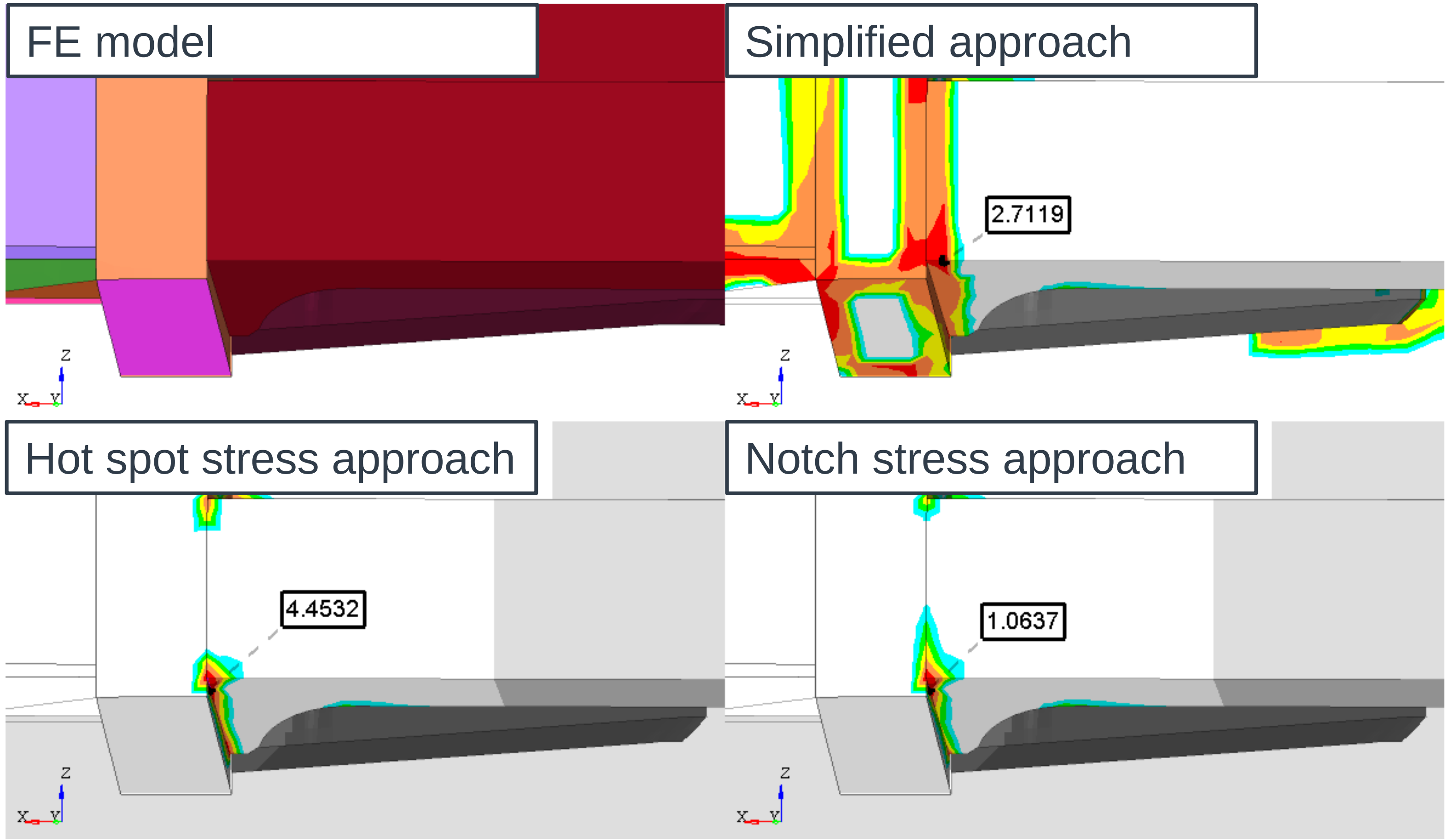
Simulated and real world testing utilization

Proving ground testing

Degree of utilization a=5.5

Good correlation between simulation and testing ✓
→ Weld model for detailed analysis

Virtual proving ground testing



Simulated and real world testing utilization

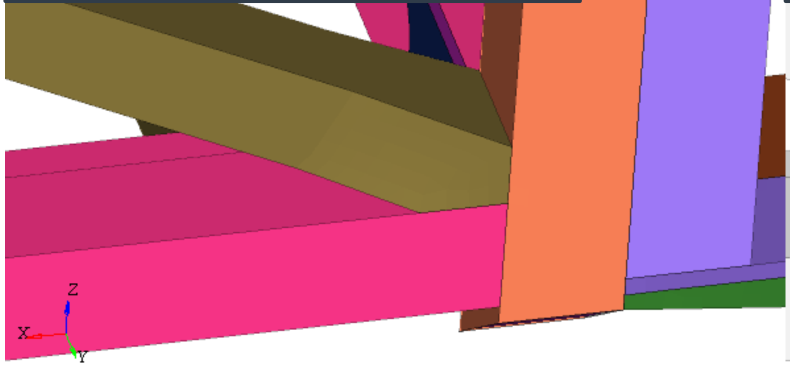
Proving ground testing

Degree of utilization a=5.5

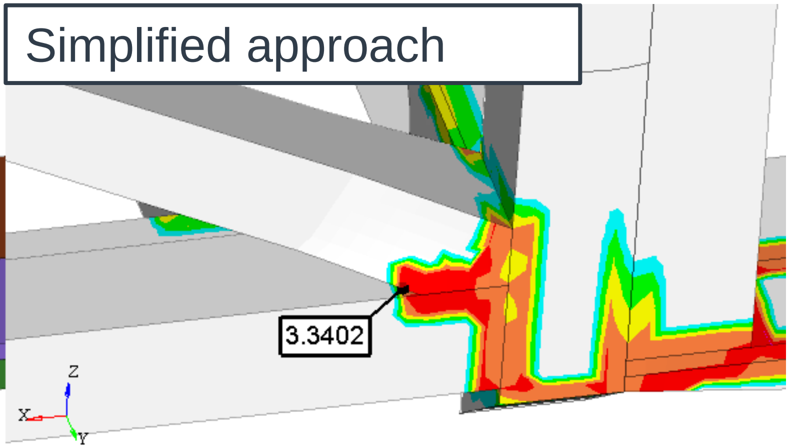
Good correlation between simulation and testing ✓
→ Weld model for detailed analysis

Virtual proving ground testing

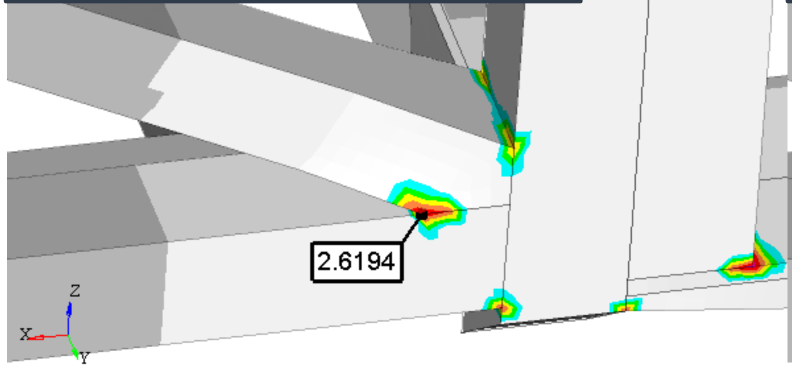
FE model



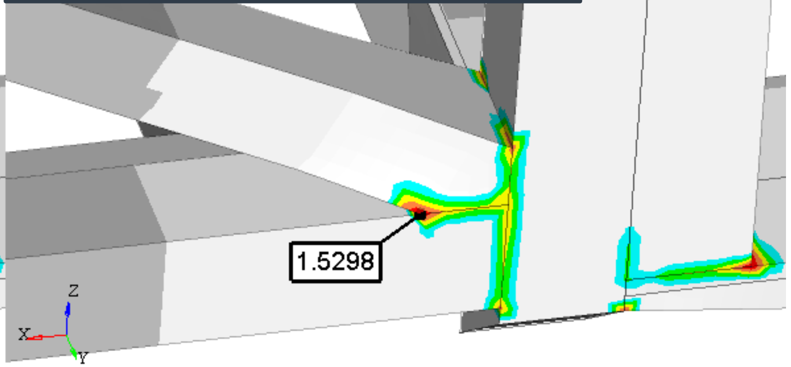
Simplified approach



Hot spot stress approach



Notch stress approach



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CONCLUSION AND OUTLOOK

Conclusion and outlook

Conclusion

- Virtual proving ground testing at MAN
- Modelling of welds
  - Simplified approach
  - Hot spot stress
  - Notch stress
- Comparison of stress data from simulation and measurement

Good correlation of stresses between measurement and simulation ✓

- Comparison of simulated utilization at hotspots and proving ground lifetime

Good correlation between virtual proving ground test and real world test ✓

Outlook

- Extension of notch factor database
- Modelling of damping effects
- Identification of critical modes
- Parallelization of FEMFAT scratching

der Bundeswehr
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Thank you very much for your attention

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